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DIRECTIONS
FOR MAKING
THE BEST COMPOSITION
FOR
The Metals of Reflecting Teleſcopes;
AND THE METHOD
OF CASTING, GRINDING, POLISHING,
AND GIVING THEM
THE TRUE PARABOLIC FIGURE.

BY

The Rev'd JOHN EDWARDS, B.A.

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DIRECTIONS for making the beſt Compoſition for the Metals of REFLECTING TELESCOPES, *and the Method of caſting, grinding, poliſhing, and giving the great Speculum the true parabolic Figure.*

By the Rev'd JOHN EDWARDS, *B. A.*

THE Methods in general uſed for caſting, grinding, and poliſhing the Metals for Reflecting Teleſcopes being well known to Workmen, and having been treated of in the moſt full and ſatisfactory Manner in Dr. *Smith*'s Optics, and alſo by Mr. *Mudge* in the Philoſophical Tranſactions, Vol. LXVII, Part I, I ſhall not dwell upon theſe Points, but ſhall add ſuch Directions and Obſervations of *my own* as I have found by Experience to anſwer much better than the Methods taught by thoſe Writers. Some Teleſcopes conſtructed by me have been tried by the Rev'd Dr. MASKELYNE, Aſtronomer Royal, and found very greatly to excell in Brightneſs *, and to equal in other Re-

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* Mr. *Edwards*'s Teleſcopes ſhew a white Object perfectly white, and all Objects of their natural Colors; very different from common Reflecting Teleſcopes, which give a dingy copperiſh Appearance to Objects. I found, by a careful Experiment, that they ſhew Objects as bright as a treble Object-glaſs Achromatic Teleſcope, both being put under equal Circumſtances of Areas of the Aperture of the Object-metal and Object-glaſs, and equal magnifying Powers; whereas the Diameter of the Aperture of a common Reflecting Teleſcope muſt be to that of an Achromatic Teleſcope as 8 to 5, to produce an equal Effect.
NEVIL MASKELYNE.

ſpects,

ſpects, Teleſcopes of the ſame Size, conſtructed by the beſt Artiſts in London.

Of the beſt Compoſition for Reflecting Specula.

THAT I may not be tedious upon this Point, it may be neceſſary to acquaint my Reader, that I have made Experiments upon the following Metals and Semi-metals, in order to diſcover a Compoſition for a Speculum, which ſhould reflect the greateſt Quantity of Light, and conſequently be capable of receiving the fineſt Poliſh. I combined them in ſeveral Proportions, and ground and poliſhed them. The Metals and Semi-metals I tried were Silver, Platina, Iron, Copper, Braſs, Lead, and Tin; Crude Antimony, Regulus of Antimony, Martial Regulus of Antimony, Arſenic, Biſmuth, Zinc, and Antimony combined with Cawk-ſtone *. Having tried many Compoſitions of them (ſee the Appendix) I found that 32 Ounces of Copper, with 15 or 16 Ounces of Grain Tin (according to the Purity of the Copper) with the Addition of a little † Braſs and Arſenic; viz. one Ounce of each to the above Proportion of Copper and Tin, will form a Metal capable, when poliſhed in a proper Manner, of reflecting much more Light than any other Metal that has as yet been offered to the Public. When I ſay that the Proportion of Tin is from 15 or 16 to 32 Ounces of Copper, I would be underſtood, that the Proportion of Tin will not always be accurately the ſame, as Copper will take more or leſs Tin to perfectly ſaturate it according to its Purity. It might be of Uſe previouſly to purify the Copper as much as poſſible. A very little Experience in theſe Matters will enable any one to know exactly when the Copper is completely ſaturated; as the Compoſition will, if broken, appear of a moſt beautiful bright and glaſſy Nature, very much reſembling the fine Face of Quickſilver. My Method to aſcertain that Point accurately, is to melt 32 Ounces of Copper, and to add to it, when ſufficiently fuſed, 15 Ounces of Tin, and to pour the Mixture into an Ingot: Then to a certain known Portion of this Compoſition, I add a very ſmall, but known Portion of Tin; and thus, by a few Trials, I can eaſily obtain the Point of complete Saturation, and the Maximum of Perfection. Having then aſcertained what Portion of Tin I added to the above known Quantity of the Compoſition, I add the proportional Quantity of Tin to the *Whole*, when melted a Second Time. Thus, if I find, that I muſt add a Quarter of an Ounce of Tin to One Pound of the Compoſition, ſo as to obtain the *ne plus ultra* of * Brilliancy; then I know, that, when I ſhall melt the Remainder of the Metal a Second Time, in order to caſt the Speculum, I muſt add One Ounce of Grain Tin to Four Pounds of the Compoſition, made according to the Proportion of 32 Ounces of Copper to 15 Ounces of Tin. The *Arſenic* muſt be added in the *Second* Melting, when the Speculum is intended to be caſt, as the Heat of the Mixture, in the * *Firſt* Melting, is ſo great as to render the moſt Part of the Arſenic volatile, and in a great Meaſure prevent its Action upon the Metals, It is ſomewhat ſingular that *Arſenic*, though particularly recommended by † Sir ISAAC NEWTON for this Purpoſe, ſhould be haſtily thrown aſide by the Founders, as well as paſſed over unnoticed by the Writers upon this Subject. This imprudent Diſuſe of it I can only attribute to the diſagreeable Fumes or Vapours which ariſe when it is introduced into the Crucible to the melted Mixture, which may produce diſagreeable Effects upon the Operator, if proper Care is not taken to prevent them from being received into the Lungs ‡. All the Precaution neceſſary, is to bruiſe the Arſenic coarſely, and introduce it into the Crucible with a Pair of Tongs, having tied it up in a Piece of Paper; giving it then a Stir with a wooden Spatula, retaining your Breath, avoid it till you can ſee no more Vapours ariſe from the Crucible, when the Metal will be ready to be poured into the

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* See a moſt curious Experiment upon Cawk-ſtone and Antimony in the Philoſophical Tranſactions, No. cx.

† If One Ounce of Silver be added to this Compoſition, the Metal will be much better and whiter.

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* If too much Tin ſhould be added; viz. if 17 Ounces of Tin is put to 32 Ounces of Copper, the Compoſition is not *brilliant* when broken, but of a *grey blue* and dull Colour. If the Quantity of the Tin be further increaſed, the Metal will become almoſt *black*.

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* Sir ISAAC NEWTON melted the Copper firſt, then added the Arſenic, and laſtly the Tin; as without Doubt he knew that the Tin ſhould remain in a fluid State the ſhorteſt Time poſſible. It is true that Sir ISAAC added the Arſenic to the melted Copper; but as he well knew that a great Part of it would be rendered volatile, he therefore added a very large Quantity of it; viz. Arſenic 1 to Copper 6.

† See Dr. *David Gregory*'s Optics by Dr. *Brown* and Dr. *Deſaguliers*, p. 219; or Philoſophical Tranſactions, Nº 81.

‡ I have been aſſured by Two ingenious experimental Philoſophers, that the Fumes of Arſenic, even when the Garlic Smell is very ſtrong, are not in the leaſt prejudicial to the Lungs.

NEVIL MASKELYNE.

Flaſks to caſt the Speculum. The great Uſe of *Arſenic*, in this Compoſition, is to render the Metal much more compact and ſolid, and indeed much more *beautiful*, as any one may experience by comparing the Compoſition *with* Arſenic, with the ſame Compoſition of Copper and Tin *without* Arſenic. In general I find One * Ounce of Arſenic ſufficient for One Pound of the Metal. A much greater Quantity of Arſenic may be uſed without any Diſadvantage to the Beauty or Compactneſs of the Metal; but then it is too apt to tarniſh, if expoſed to the Air for ſome Time: Three Quarters of an Ounce or an Ounce of Arſenic to One Pound of Compoſition will not tarniſh in the leaſt Degree. Indeed the Reaſon why the Metals, generally made Uſe of for Specula, tarniſh when they are much expoſed to the Air, is becauſe the Quantity of Copper in their Compoſition is not nearly ſaturated, and the Acid contained in the Air, by acting upon it, extracts the Copper from the Tin, and turns the Metal into a dirty or dingy coloured Speculum, and which (beſides the great Loſs of Light) cauſes the common Reflecting Teleſcopes to ſhew all Objects of a dirty red or yellowiſh Colour. This, however, is not the Caſe in the Metals made of the above Compoſition; for, as the Copper is completely ſaturated, the Air cannot act upon it in the leaſt Degree. I muſt not, however, paſs over One Caution in the Mode or Manner of melting the Compoſition, and that is, that the Copper muſt be melted firſt of all, and rendered as fluid as poſſible, then the Braſs and Silver muſt be added, and the

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* One Ounce of Arſenic will however ſufficiently act upon and bind Three Pounds Weight of the Metal, ſo that it ſhall never tarniſh by the Air.

Whole fluxed with the common black Flux, made of Two Parts of Tartar to One of Nitre, or by ſtirring the melted Mixture with a wooden Spatula of *Birch*, and made as fluid as poſſible. The Tin muſt now be added, and the Whole poured off immediately after it is once ſtirred together; for if the Mixture is *continued* on the Fire ſome time after the Tin is added to it, it will always prove porous afterwards, though it be melted a Second Time, with the ſmalleſt Heat poſſible. As I ever found this to be the Caſe, I naturally conjectured that the Metal would be moſt ſolid and free from Pores, when the Tin remained the leaſt Time poſſible in a State of Calcination. Experience determined the Truth of my Conjecture, and I now find that the beſt Method poſſible to make this Compoſition to the greateſt Advantage is, to melt the Copper as fluid as poſſible, and flux it with the black Flux; to melt the Tin in a ſeparate Crucible by itſelf; to take the Two Crucibles out of the Fire, and pour the melted Tin into the fluid Copper; and ſtir it inſtantly with a wooden Spatula, and pour the Whole immediately into a large Quantity of cold Water. The ſudden Chill from the cold Water divides the melted Maſs into an infinite Number of ſmall Particles, and by that Means cools it inſtantaneouſly, and conſequently prevents the Tin from calcining ſenſibly; and hence I have always found, that in the Second Melting, the Compoſition was entirely free from Pores, even though no *Arſenic* had been employed. Yet the Addition of *Arſenic* ever rendered it much more compact, and indeed * ſpecifically ſically heavier, as well as more brilliant and beautiful. On reverſing the Proceſs, if the Tin is put into the Bottom of the Crucible, and the Copper at the Top of it, which I have frequently done, the Copper will melt with a very little Heat; whereas, when Copper is put into the Crucible by itſelf, it requires a pretty ſtrong Heat to cauſe it to melt. When I firſt made Uſe of this Method, I imagined I had diſcovered a very eaſy one to melt the Copper, and conſequently I thought I had greatly improved the common Method; and, as Mr. *Mudge* aſcribed the Pores in the Metal to the Tin being calcined by the great Heat of the fluid Copper at its Firſt Melting, I naturally expected to find the Metal, made by the above Proceſs, totally free from Pores, eſpecially in the Second Melting, as the Heat was conſiderably leſs than if the Copper had been melted firſt by itſelf. However I always found it full of Pores, much more porous than I had ever ſeen it before. For ſome time I could not diſcover the true Cauſe, having no Idea that the Pores were owing to the Tin remaining ſo long in the Fire in a fluid State, and therefore in a State of perpetual Calcination. I attributed the Poroſity of the Metals, which I made of this Compoſition, to a Multitude of Cauſes, till thoroughly tired of Experiments and Conjectures to aſcertain the true Reaſon, I was determined to melt the Copper firſt and the Tin afterwards, as I had always done before I dropped upon this improved Method, as I imagined. The Reſult was, the Metal was infinitely more compact and much leſs porous. By melting the Copper firſt and then adding the Tin to it, I ſoon diſcovered that the longer the Tin remained in the Fire, the more porous the Metal turned out; and, *vice verſâ*, the ſooner I poured

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* The ſpecific Gravity of the Compoſition itſelf is 8,78; with the Addition of 1 oz. of Arſenic to 1 lb. of Metal is 8,89.

it off, after I had added the Tin, the more compact and free from Pores it proved. From theſe Obſervations I determined to try the Effect of adding the Tin in a fluid State to the melted Copper, and to cool the Whole immediately, to prevent, as far as I was able, Calcination from taking Place. Experience confirmed my Conjectures; and I ſoon found that by pouring the whole melted Maſs, the Inſtant they were mixed and ſtirred together, into cold Water, the Metal always proved, in the Second Melting, ſolid and much more compact, beautiful, and white, than I had ever ſeen it by any other Proceſs. One Thing I cannot paſs over, as it affords a clear Proof of the Uſe of *Arſenic* in rendering the Metal much more ſolid and compact, and conſequently more free form Pores than if no *Arſenic* had been uſed in the Compoſition. Whenever I made the Compoſition, by melting the Copper and Tin together, by putting them into the Crucible at the ſame time and melting them down together, the Metal was always porous, as I obſerved before: However frequently I melted it afterwards, and though I gave it no more Heat than was barely neceſſary to melt it, yet if I added to this very porous Metal, after it was melted, a ſmall Quantity of *Arſenic*; viz. an Ounce to One Pound of the Metal, it was really aſtoniſhing to ſee how much better the Metal turned out, being conſiderably harder than before, and incomparably leſs porous. I mention this Circumſtance, which any one may eaſily try, to ſhew the very great Advantage of uſing a ſmall Portion of *Arſenic* to render it more compact, and, as Sir ISAAC NEWTON juſtly * obſerves, more *white* than before. The Uſe of the ſmall Portion of Braſs in this Compoſition is to render it more tough and not ſo exceſſive brittle, as this Compoſition without the Braſs would prove. A ſmall Portion of Silver will make the Metal much whiter, though if too much is added it is apt to be porous. Having ſaid ſo much relative to the Compoſition of the Metal, which indeed is a capital Article, I paſs on to

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* See Appendix to *Gregory*'s Optics, p. 219; or the Philoſophical Tranſactions, N° 81.

The Manner of caſting the Metal.

THE Sand moſt proper for caſting this, and indeed any other Metal, is a fine Sand, with no more Loam or Clay mixed with it naturally than is abſolutely neceſſary to make it tenacious enough to adhere together when properly moiſtened. If too much Clay is mixed by Nature with the Sand, it will always *blow* the Metal in different Directions, ſometimes indeed to the great Danger of the Operator. On the contrary, if the Sand does not contain a ſufficient Quantity of Clay, it will not remain in the Flaſks, or take a proper Impreſſion from the Pattern or Model. The beſt Sand I could ever meet with for the Purpoſe of caſting Specula, is the common *Highgate* Sand (near *London*) generally uſed by the *London* Founders. It ſhould be as little wet as may be, and well beaten, but not too hard. The Flaſks ſhould be at leaſt Two Inches wider than the Metal intended to be caſt. If the Sand is not of a ſufficient Thickneſs round the Metal it will inſtantly become dry when the hot fluid Metal is poured into it, and conſequently will contract, and of courſe the fluid Metal will run out of the Flaſks. A proper Thickneſs of Sand will, however, prevent this Accident. The Metal or Pattern ſhould be made of Braſs or hard Pewter, and muſt be a little larger and thicker than the Speculum intended to be caſt from it; as the Thing caſt is always a little leſs than the Pattern, owing to its contracting, a ſmall Degree, in cooling. A wooden Pattern will not quit the Sand near ſo well as one made of Metal; beſides Wood will always warp by the Moiſture of the Sand, and conſequently will give a falſe Figure or Form to the intended Speculum. As the Compoſition I have given for the Speculum is the *hardeſt*, and conſequently the moſt brittle of any Metal yet known; ſo it is the moſt difficult to caſt. The common Manner of caſting other Specula will not avail, in the leaſt Degree, here; and it was a very conſiderable Time before I found out a certain and infallible Way to caſt them free from Faults or Flaws in the Face. In general they cracked in the cooling, from the Moiſture of the Sand. The only Method poſſible to caſt them well (for indeed I have tried many Methods) is to caſt them with the Face *downwards*. The Ingate or Git ſhould be at the Back of the Metal, and at the very Edge of it; its Breadth, where it joins the Metal, ſhould be at leaſt Half the Diameter of the Metal, and its Thickneſs muſt be Half the Thickneſs of the Metal at the Edge; the upper Part of the Git ſhould contain as much Metal, at leaſt, or even more, than the Speculum itſelf. I could give my Reader ſufficient Reaſons for every Part of the Proceſs above directed, but I might be thought too tedious: Suffice it then that I inform him, that he will find theſe Directions will anſwer in Practice;

and I believe, I can ſay, that no one whatever can caſt Specula, of this brilliant and brittle Compoſition, by any other Means than what I have now pointed out. When the Pattern, with its Ingate or Git, is taken out of the Sand, Ten or a Dozen ſmall Holes ſhould be made through the Sand, at the Back of the Mould, with a ſmall Wire or common Knitting-needle, to permit the *Air* to eſcape, as the Metal is poured into the Mould. I have found by Experience, that ſeveral ſmall Holes are infinitely better, for that Purpoſe, * than One large Hole. When the Metal is melted a Second Time, which muſt be done with as ſmall a Degree of Heat as poſſible, add the proportional Quantity of crude Arſenic in coarſe Powder, and ſtir it well with a wooden Spatula; when the Fumes are gone off, take the Metal off the Fire, take away the Droſs, and add Half an Ounce or an Ounce of powdered Roſin, or equal Parts of powdered Roſin and Nitre, in order to give the Metal a good Face; ſtir it well with a Stick, and pour it immediately into the Flaſks. When the Git is filled up with the fluid Metal, ſtrike the Flaſks gently, ſo as to ſhake or jog the Metal in them in a ſmall Degree; this will prevent any Flaws in the Face from any Air-bubbles being lodged there. When the Metal has remained in the Flaſks for a few Minutes, ſo as to become entirely ſolid, open the Flaſks while the Metal is red-hot (it cannot crack in this State, though it is expoſed to the Air, as all Metals are malleable when they are red-hot) and take out the Speculum with a Pair of Tongs, laying hold of it by the Git, but take Care to keep the Face downwards to prevent it from ſinking. Force out the Sand from the Hole in the Middle of the Mirror, with a Piece of Wood or Iron, and place the Speculum in an Iron Pot with a large Quantity of hot Aſhes or ſmall Coals, ſo as to bury the Speculum in them a ſufficient Depth. If the Sand is not forced out of the Hole, in the Manner above directed, the Metal, by ſinking as it cools, will embrace the Sand in the Middle of the Speculum ſo tight as to cauſe it to crack before it becomes intirely cold. And if the Metal is not taken out of the Sand, and put in a Pot with hot Aſhes or Coals to anneal it, I can aſſert, that the Moiſture from the Sand will always break the Metal. Let the Speculum remain in the Aſhes till the Whole is become quite cold. The Git may be eaſily taken off by marking it round with a common fine half-round File, and giving it then a gentle Blow. The Metal is then to be rough-ground and figured.

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* If ſeveral ſmall Holes are made for the Air to eſcape, the Back of the Metal will be caſt much neater than if One Hole only is uſed for this Purpoſe. Beſides, when One Hole only is uſed to let the Air eſcape, the Metal is very apt to crack in that Place, owing to the Sinking of the Metal in cooling.

Of the rough-grinding and figuring the Speculum.

IN rough-grinding, figuring, and poliſhing the Metal *Two* Tools only are neceſſary, beſides a common Grindſtone. One chief Reaſon why Workmen do not give a good Figure to their Specula, is becauſe, by purſuing Dr. *Smith*'s or Mr. *Mudge*'s Method, they uſe too many Tools, which in a great Meaſure deſtroy each other's Effects. As

Nature always acts in the moſt ſimple Manner, ſo if we could always imitate her in this Reſpect we ſhould arrive at a much greater Degree of Excellence in moſt of our mechanical Purſuits. Beſides, the Tools generally made Uſe of by Workmen are conſiderably too large in Diameter, ever to give a correct and uniform Figure. All the Tools I make Uſe of are a Rough-grinder compoſed of Lead and Tin mixed together, or elſe of Pewter; this Rough-grinder ſerves alſo for a Poliſher; this Tool, with a Bed of Stones or Hones, are all that are neceſſary. A Bruiſer (as directed by Dr. *Smith* and Mr. *Mudge*) is totally unneceſſary, cauſes conſiderable more Work, and, after all, is really detrimental. The beſt Method I have ever found to rough-grind the Speculum, is to grind the Surface of it quite bright upon a * common Grindſtone, made nearly to the Figure or Focus of the Speculum by a Gage. Take it then to a convex Tool made of Lead and Tin, or elſe of Pewter, and grind the Metal upon it with fine Emery. This Emery, however fine it may be, will break up the Metal very much; but we can eaſily cure that Proceſs, as I ſhall ſhew hereafter. This Tool or Rough-grinder ſhould be made of an *elliptical Form*, and not circular (for a Reaſon I ſhall point out hereafter) and of ſuch Dimenſions that the ſhorteſt Diameter of the Ellipſe ſhall be equal in Breadth to the Diameter of the Mirror, and the longeſt Diameter of the elliptical Tool ſhould be to the ſhorteſt Diameter in the Proportion of 10 to 9 accurately, for a Reaſon to be mentioned hereafter. The Manner of working or figuring the Metal upon this Tool, and indeed upon all the ſucceeding Tools, is taught in Dr. *Smith's* Optics, or the before-mentioned Volume of the Philoſophical Tranſactions. I ſhall refer my Reader to thoſe Publications, as I only mean to give *my own* Improvements. When the Metal is brought to a true Figure, it muſt be taken to a convex Tool, formed with ſome Stones from a Place called *Edgedon*, in *Shropſhire*, ſituated between *Ludlow* and *Biſhop's Caſtle*. Theſe Stones or Hones are of a fine Grain, and will eaſily cut the Metal and bring it to a fine Face. Indeed the blue * Hones, uſed in general by the Opticians for this Purpoſe, will ſcarce touch the Metal, and it will be a laborious Undertaking to bring the Metal to a fine Face, ſo as to take out all the Breaks up from the Emery, by the common blue Hones. By Means, however, of the above-mentioned Stones they may eaſily be ground and truly figured. The Bed of Stones ſhould be of a circular Figure, and but very little larger than the Metal intended to be figured upon it; viz. about Two Tenths of an Inch, but not more, for a Speculum of Four or Five Inches in Diameter. If the Tool is made conſiderably larger than the Metal, it will grind the Metal perpetually into a larger Sphere, and by no Means of a good Figure: If the Metal and Tool are of the ſame Size exactly, the Metal will work truly ſpherical; but it is apt to ſhorten its Focus leſs and leſs, unleſs the Metal and Tool are worked alternately upwards. It had, therefore, better be made a little * larger than the Mirror, when it will not alter its Focus. Too much Water ſhould not be uſed at a Time upon the Hone Pavement, or the Figure will be very bad, which may eaſily be ſeen by the Face of the Metal appearing of different Degrees of Brightneſs in different Parts of it. When the Metal is brought to a very fine Face and Figure by the Bed of Stones, it is ready to receive a Poliſh: But before I ſhall give my Directions concerning the Manner of poliſhing it, I muſt mention a Circumſtance or two I had inadvertently paſſed over. The Metal muſt not be caſt too thick, or it will never take the parabolic Figure intended to be given to it. The beſt Proportion I have found for this Purpoſe is, a Metal of 4¼ Inches Diameter and 18 Inches Focus ſhould be Four Tenths of an Inch thick at the Edge of it: The Back of the Mirror ſhould be convex to ſtrengthen it, and to cauſe it to ſpring and adhere to the Poliſher uniformly. Its Convexity ſhould be equal to its Concavity on the Face, that the Metal may be every-where of an equal Thickneſs. The Handle ſhould be made of Lead, of the ſame Convexity and Concavity as the Metal, its Thickneſs about double that of the Metal, and its Diameter Three Fourths of that of the Speculum; it ſhould have a Hole in the Middle, with a Copper or Iron Screw on it, ſo as to put it, together with the Mirror, to which it is faſtened with Pitch, on a Collar Lathe, in order to ſmooth and finiſh the Edge of the Metal, which may be done by holding a fine File to it, when in the Lathe, at the firſt, and afterwards one of the above-mentioned Stones.

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* The Grindſtone may eaſily be brought to the Form of the Gage, by holding the ſharp Edge of an Iron Bar againſt it, while it is turned round, till ſo much is worn away from its Surface, as ſhall cauſe it to take the true Curvature of the Gage.

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* Should any one however make Uſe of the common blue Hones, he ſhould uſe as little Water as poſſible when the Metal is put upon them, as they will cut much better when barely wet, than if much Water is uſed upon their Face.

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* About One Twentieth-part greater in Diameter.

Of poliſhing the Metal, and giving it the true parabolic Figure.

THE Rough-grinder of an *elliptical* Form is now to be covered with common Pitch. I generally make my own Pitch by boiling Tar in a Ladle, or Crucible, over a very ſlow Fire, till it becomes of the Conſiſtence I require; for a great Nicety is required in the Degree of the Hardneſs of the Pitch. The harder the Pitch is the better Figure it will give to the Metal, as it does not alter its Figure in working as ſoft Pitch does; beſides the Metal will acquire a Luſtre upon a Poliſher moderately hard, ſo as to ſhew Objects reflected from it as vivid and as near their natural Colour as poſſible; but, if the Pitch is too ſoft, ſome of its fineſt Particles will always adhere to the Face of the Metal, and form a very fine and thin Cuticle or Covering upon its Surface. This Circumſtance is rendered very evident by viewing any white Object in the Metal (a Sheet of white Paper, for Example) when that fine Cuticle or thin Surface of the Pitch upon the Speculum will cauſe it to ſhew the Object of a dingy brown Colour, and not of its genuine Whiteneſs. Pitch may be eaſily made harder by adding to it a proper Quantity of Roſin. I often uſe equal Quantities of Pitch and Roſin, ſo as to make the Mixture juſt ſo hard when cold as to receive an Impreſſion from a moderate Preſſure of my Nail. A Poliſher made with Pitch and Roſin has this Advantage; viz. though it is hard, yet it is not ſo brittle as when Pitch only is uſed, and made hard by boiling it, and conſequently not ſo liable to break or chip off at the Edges, and thereby ſcratch the Metal. Pour the melted Pitch and

Roſin, when pretty cool, from the Crucible upon the * elliptic Tool, ſo as to cover it every where when ſpread upon it with an Iron Spatula, about the Thickneſs of a Half-crown Piece. If the Covering is too thin it will continually alter its Figure, by the Heat it acquires in working the Metal upon it, and thereby give a bad Figure alſo to the Speculum. When it is ſomewhat cool, lay a Piece of Writing Paper upon the Surface of the Pitch, and gently preſs the Mirror upon the Paper; inſtantly pull the Paper from off the Pitch, after you have preſſed the Mirror upon it, elſe it might adhere to the Pitch, and you will find the Poliſher will be nearly figured to the Form of the Speculum. If it has not taken an exact Figure every where, which would appear by the fine Marks of the Grain of the Paper upon the Pitch, gently warm the Surface of the Pitch, and repeat the Operation as before, till you have formed it of the † exact Figure of the Metal. With a Penknife take away now all the ſuperfluous Pitch from the Edge of the Poliſher, and with a conical Piece of Wood form the Hole in the Middle accurately round: In other

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* The elliptic Tool muſt be made pretty warm, or the Pitch will not adhere to it.

† When the Poliſher is brought to its true Figure, gently warm it at the Fire, and with the Edge of a Knife divide it into ſeveral Squares by preſſing the Edge of the Knife gently upon the Pitch; theſe Squares, by receiving the ſmall Portion of the Metal that works off it in poliſhing, will cauſe the Figure of the Speculum to be more correct than if no ſuch Squares had been made.—The Poliſher may alſo be formed, without the Writing-paper, by dipping the Mirror into cold Water, and afterwards preſſing it upon the Surface of the Pitch (when it is ſomewhat cool) and by repeating this Operation till it has taken the exact Figure of the Metal

Words, let the pitchy Surface be every where of the exact Size and Shape as the Lead Tool which is under it. It may be neceſſary to mention that the Hole in the Middle of the Poliſher ſhould go quite through the Tool (for a particular Reaſon) and ſhould be made of the ſame Size, or ſomewhat leſs, than the Hole in the Middle of the Speculum. This is a neceſſary Caution, and indeed I have always found that ſmall Mirrors, without any Hole in the Middle, will poliſh much better and the Figure will be more correct, if the Poliſher has a Hole in the Middle of it. The Powder I prefer above all others to give a moſt exquiſite Luſtre, is *Colcothar of Vitriol* and not *Putty*. *Putty* gives Metals a white Luſtre, or, as Workmen call it, a Silver Hue; but good Colcothar of Vitriol will poliſh with a very fine and high black Luſtre, ſo as to give the Metal finiſhed with it the Complexion of poliſhed Steel. To know if the Colcothar of Vitriol is good, put ſome of it into your Mouth, and if you find it diſſolves away it is good; but if you find it hard and cranch between your Teeth, then it is bad and not well burned. Good Colcothar of Vitriol is of a deep red or a deep purple Colour, and is ſoft and oily when rubbed between the Fingers: Bad Colcothar of Vitriol is of a light red Colour, and feels harſh and gritty. The Colcothar of Vitriol ſhould be levigated between Two Surfaces of poliſhed Steel, and wrought with a little Water; when it is worked dry you may add a little more Water to carry it lower down to what Degree you pleaſe. When the Colcothar of Vitriol has been wrought dry Three or Four Times, it will acquire a black Colour, and will be low enough or ſufficiently fine to give an exquiſite Luſtre. This levigated Colcothar of Vitriol I put in a ſmall Phial, and pour ſome Water upon it, and afterwards I uſe it for poliſhing the Metals in the ſame Manner that waſhed Putty is always directed to be made Uſe of for that Purpoſe. I always put on a large Quantity of waſhed Colcothar of Vitriol at once, ſo as to ſaturate the Pitch and form a fine Coating of the Colcothar, and very rarely make Uſe of a Second Application. If a ſecond or third Application of Colcothar ſhould be found neceſſary to bring the Metal to a high Luſtre, or to take out any Scratches upon its Face, uſe it very ſparingly, or you will deſtroy the Poliſh you have already attained. When the Metal is nearly poliſhed, it will always generate ſome black Mud upon the Surface of the Mirror, and alſo upon the Tool. Wipe it now away from the Face of the Metal, with ſome very ſoft Waſh-leather; though if too much of this Mud be taken away, it will not poliſh ſo well. Indeed a little Experience in theſe Matters will better ſuffice than a Volume written upon the Subject.

In regard to the *parabolic Figure* to be given to the Metal, no particular Caution is required in the poliſhing; the *elliptical Tool* will always cauſe the Speculum to work into an accurate parabolical Figure, ſuppoſing the tranſverſe and conjugate Diameters bear the true Proportion to each other, and the Metal is not too thick to prevent it always from adhering firmly and uniformly to the Poliſher. Should the Pitch prove too ſoft, it will give way, and alter the Figure a little. This Circumſtance will render the Figure of the Mirror ſometimes a ſmall Degree ſhort of the Parabola, and ſometimes a very little beyond it; but by a little Perſeverance the correct Figure is very eaſily acquired. I could very eaſily give the Reader the Reaſon why an *elliptical Tool* of a proper Proportion will always give a parabolical Figure; and, if the tranſverſe Diameter is increaſed, it will then always give an hyperbolical Figure; but as I am writing upon the *practical* Part of making Reflecting Teleſcopes, and not the *Theory*, I will not offend his Patience. To convince any one of the Certainty of my Aſſertions; let him poliſh a Metal 2½ Inches Diameter and 9½ Inches Focus, upon an *elliptical Tool*, whoſe Diameters are 2½ and 3 Inches, and I can aſſert he will always find the Metal, when poliſhed (if it is not too thick) *beyond* the Parabola, or it will always prove hyperbolical. If he poliſhes it upon a *circular* Tool in the common Way, with croſs Strokes in every Direction poſſible, uſing firſt a few round Strokes every Time he changes his Poſition, he will find it will always prove ſpherical, and conſequently *ſhort* of the Parabola. A very little Experience in theſe Matters will convince any one of the Eaſe and Certainty of giving the great Speculum a parabolic Figure by poliſhing it in a common Manner only, with croſs Strokes in every poſſible Direction, upon an *elliptical Tool* of the proper Dimenſions, in which, for common Foci and Apertures; viz. 2½ to 9½ Focus, or 3,8 Inches in Diameter to 18 Inches Focus, the Diameters ſhould be 10 to 9. The ſhorteſt Diameter of the *Ellipſe* being accurately the ſame as the Diameter of the Metal, and the longeſt Diameter of the Ellipſe to the ſhorteſt Diameter as 10 to 9.

Ludlow,
July 19th, 1781.

JOHN EDWARDS.

APPENDIX.

An Account of ſeveral Compoſitions of Metals and Semi-metals, on which Trials were made to find out the moſt proper Mixture for the Specula of Reflecting Teleſcopes,

By the Rev'd JOHN EDWARDS, *B. A.*

1 COPPER and Tin equal Parts—very bad, ſoft, and of a blue Colour.

2 D° with Arſenic $\frac{1}{8}$—but little different from the 1ſt.

3 Tin 2, Copper 1—much worſe than the preceding ones.

4 Copper 32, Tin 16, Arſenic 4, Nitre 4—black and brittle.

5 Copper 6, Tin $1\frac{3}{4}$, Arſenic 1—very indifferent.

6 Copper 32, Tin 14, Arſenic 2—a very good Metal.

Note, By Tin, I always mean Grain-tin.
4 The Nitre was added to fix the Arſenic.

7 Copper 32, Tin $13\frac{1}{2}$, Arſenic 1—not quite ſo good as 6th.

8 Copper 32, Tin $13\frac{1}{2}$, Arſenic $1\frac{1}{2}$—a good Metal.

9 Copper 32, Tin 15, Arſenic 2—much better than any of the above.

10 Copper 6, Tin 2, Arſenic 1—compact, but very yellow when poliſhed.

11 Copper 3, Tin $1\frac{1}{4}$—compact, and whiter than the 10th.

12 Copper 32, Tin $14\frac{1}{2}$—a pretty good Metal, but poliſhes too yellow.

13 Copper 32, Tin 15, Arſenic 2, Flint-glaſs in Powder 3—very bright, but rotten.

14 Braſs 6, Tin 1—compact, but too yellow.

15 Two Parts of 11th Compoſition and 1 Part of 14th Compoſition—compact, but much too yellow when poliſhed.

16 Braſs 5, Tin 1—ſomewhat whiter than 14th.

17 Braſs 4, Tin 1—a good Metal, but rather yellow.

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13 Flint Glaſs was added as a Flux. See *Shaw*'s Chymiſtry, p. 255.

Note, The 10th is the Compoſition of Sir *Iſaac Newton*. See Appendix to *Gregory*'s Optics, p. 221. The 11th, 14th, and 15th are the Compoſitions of Mr. *Molyneux*. See *Smith*'s Optics, Vol. II. P. 304. And the 12th is the Compoſition of Mr. *Mudge*. See Philoſ. Tranſ. Vol. LXVII. P. 298.

19 and 21. Theſe Compoſitions are mentioned by *Neri* and *Kunchall* in *Neri*'s Art of Glaſs Making. Surely they never tried thoſe Compoſitions themſelves, but took them upon the Report of other Authors, as the 19th will not take a good Luſtre, and the 21ſt is very ſoft like hard Pewter, therefore highly improper for Specula, which ſhould be as hard as poſſible.

18 Braſs 4, Tin 1, with Arſenic $\frac{1}{10}$ —whiter than 17th.

19 Braſs 3, Tin 1—will not poliſh well.

20 Braſs 2, Tin 1—of a ſparry Nature.

21 Tin 3, Braſs 1—too ſoft, being only a Kind of hard Pewter.

22 Braſs and Arſenic equal Parts—a dirty white Colour.

23 Braſs, Copper, and Arſenic equal Parts—a dingy white.

24 Braſs and Platina equal Parts—very difficult to fuſe and mix well together, is then malleable, and of a dingy white Colour like 22d Compoſition.

25 Copper 32, Tin 14, Crude Antimony 4—black and rotten.

26 Copper 32, Tin 14, Crude Antimony 1—bluiſh and rough-grained.

27 Copper 32, Tin 15, Arſenic 4, Biſmuth 2—much too rotten.

28 Copper 32, Tin 15, Arſenic 3, Biſmuth 1—much too yellow when poliſhed, and appears alſo porous.

29 Copper 2, Zinc 1—a pale malleable Metal.

30 Copper and Zinc equal Parts—ſtill malleable and rough-grained.

31 Copper 32, Tin 15, Arſenic 4, Zinc 4—a good Metal, but does not take a high Luſtre.

32 The 31ſt Compoſition fluxed with Corroſive Sublimate—a compact and hard Metal, but rather yellow when poliſhed.

33 Copper 32, Tin 16—a moſt beautiful brilliant Compoſition, but much too brittle and rotten.

34 Copper 32, Tin 17—bluiſh and rough-grained.

35 Copper 32, Tin 18—almoſt black and rough-grained.

36 Braſs 2, Zinc 1—nearly a Gold Colour.

37 Braſs and Zinc equal Parts—a pale Gold Colour and rough-grained.

38 Spelter 4, Tin 1—very rotten.

39 Copper and Crude Antimony equal Parts—of a ſparry Nature.

40 Copper 32, Tin 15, Arſenic ¼ of the Whole—a very beautiful and brilliant Metal, but tarniſhes when expoſed for ſome time to the Air.

41 Silver and Biſmuth equal Parts—a yellowiſh white Metal, and not much harder than Silver itſelf.

42 Silver and Tin equal Parts—a white Metal almoſt like Silver itſelf, and much too ſoft for Specula.

43 Silver, Tin, and Biſmuth equal Parts—a dingy white Colour, but much harder than 41 or 42.

44 Copper 32, Tin 15, Silver 1—a beautiful compact Metal, but poliſhes rather too yellow.

45 Copper 32, Tin 15, Silver 2—not ſo white as 44.

46 Copper 32, Tin 16, Braſs 4, Arſenic 2—rather too much Tin as the Compoſition was of a bluiſh Complexion and rough-grained.

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33 Unleſs the Copper is very pure, this Compoſition will be of a dark blue Colour, as 15 Ounces of Grain Tin will generally ſaturate Two Pounds Weight of Copper.

47 Copper 32, Tin 15, Braſs 1, Silver 1, Arſenic 1—a moſt excellent Metal, being by much the whiteſt, hardeſt, and the moſt reflective I have ever yet met with.

48 Common Bell-metal—poliſhes very yellow.

49 Common Bell-metal 4, Regulus of Antimony 1—bluiſh and rough-grained.

50 Common Bell-metal 6, Regulus of Antimony 1—ſtill bluiſh and rough-grained.

51 Copper 32, Tin 14, Reg. Antim. $\frac{1}{16}$; viz. 1 oz. to 1 lb.—too much Antimony, it being of a bluiſh Colour and rough-grained.

52 Copper 32, Tin 13, Reg. Ant. $\frac{1}{16}$—bluiſh and rough.

53 Copper 32, Tin 13, Reg. Ant. $\frac{1}{32}$; viz. 1 oz. to 2 lb.—a very fine Metal in Appearance like 33.

54 Copper 32, Tin 13, Reg. Ant. $\frac{1}{40}$; viz. 1 oz. to 2$\frac{1}{2}$ lb. a beautiful Metal not much unlike 47, but not quite ſo white.

55 Crude Antimony 16, Cawk-ſtone 1 or 2 oz.—a very bright glaſſy Metal like the common

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47 This Metal, when broken, ſhould appear of a bright, glaſſy, and Quickſilver Complexion. If it appears hard and of a dead white, more Tin muſt be added (the Copper will ſometimes take 16 Ounces of Tin, if it is very pure). If it appears bluiſh and rough, more Copper or Braſs muſt be added.

49 The common Bell-metal is not a Mixture of pure Copper and Tin, but Tin mixed with Copper Ore, a little purified, before it is brought into pure Copper.

55 See this moſt wonderful Stone, and its ſtrange Effect upon Antimony deſcribed in the Philoſophical Tranſactions, N° 110. For this Stone I am much obliged to Sir JOSEPH BANKS, Preſident of the Royal Society, who favoured me with many Ounces of it.

Vitrum Antimonii, but by no Means fit for Mirrors.

56 Copper 32, Tin 16, Vitrum Antimonii made from the Cawk-ſtone 1 oz.—a very indifferent Compoſition, as the Vitrum Ant. did not differ in its Effects from Crude Antimony.

57 Copper 32, Tin 14, Lead 2—no Art can make this Compoſition mix intimately, as the Lead will always ſeparate from the Copper and Tin.

58 Copper 32, Tin 16, Reg. of Ant. 3—black and much too rotten.

59 Copper 32, Tin 16, Iron Filings 8 — a bluiſh grey Colour and rough-grained, and appeared ſomewhat like Steel when broken through.

60 59th Comp. 8 oz. Tin 1 oz.—a little whiter than 59th, but ſtill too blue.

61 Equal Parts of 59 and 60—ſtill of too blue a Colour, and not cloſe-grained.

62 Copper 32, Tin 16, Arſenic 3, Iron Filings $\frac{1}{4}$ of an oz.—a pretty brilliant Compoſition, but much inferior to 47.

63 Platina 1 oz. Braſs 1 oz. Cawk-ſtone, red hot, $\frac{1}{2}$ oz.—exceſſive difficult to fuſe, and of a dirty light-brown Colour, and ſomewhat malleable.

64 Copper 32, Tin 16, Iron-filings 4, Reg. Ant. 4, and fluxed with Corroſive Sublimate—an exceeding hard and compact Metal, but of too blue a Colour.

62 In all Compoſitions with Iron in it, the Mixture will not run ſufficiently fluid.

64 The Regulus of Antimony was added here to diſſolve or cauſe to melt the Iron-filings.

65 Copper 2 oz. Tin 1 oz. Iron-filings 1 dr. Reg. Ant. 1 dr.—too blue a Colour and rough-grained.

66 Regulus of Antimony and Tin equal Parts—ſparry and not fit for Mirrors.

67 Caſt-ſteel—will not poliſh upon Pitch either with Putty or Colcothar of Vitriol.

68 Steel 1, Tin ¼—very rough-grained and bluiſh, and not much different from Steel itſelf.

69 Steel 1, Tin 1—rough-grained and of a bluiſh Colour.

70 Steel 1, and 47th Comp. 20 Parts—rough-grained and not near ſo good as 47.

71 Steel 1, and 47th Comp. 30—not much different from 47th Comp. but not ſo beautiful and cloſe-grained.

Many other Mixtures were tried, by combining the foregoing Compoſitions in more than a hundred Variety of Proportions; but none of them were found equal to Nº 47, as that Mixture forms a Metal that is the whiteſt, hardeſt, moſt reflective, and takes the higheſt Luſtre of any Thing I have yet ſeen.

68 The Steel was melted by a Furnace of a particular Conſtruction, built on Purpoſe, as it would not melt in a Crucible and a common Air-furnace.

Of the Eye-glaſſes of Reflecting Teleſcopes.

THE Kind of Glaſs moſt proper for the Eye-glaſſes of Reflecting Teleſcopes is *Crown* Glaſs, ſuch as is uſed for the convex Glaſſes in the compound Object-glaſs of Acromatic Teleſcopes; and thoſe Pieces are the beſt, which, when laid upon a Sheet of white Paper, ſhew it of a *bluiſh* green Colour, and not of a *yellowiſh* green. *Crown* Glaſs is much preferable to *Flint* Glaſs, or indeed any other Sort of Glaſs we are acquainted with, for this Purpoſe; as it intirely deſtroys, by its Colour, all dingy or yellowiſh Appearance of Objects in Reflecting Teleſcopes (which may ariſe from the Metals not being ſufficiently white, or from a bad Poliſh) and ſhews them of their natural Colour. The dingy Appearance of Objects in the Reflecting Teleſcope is highly diſagreeable, but this will be entirely removed if the Metals are made of the 47th Compoſition, and the Eye-glaſſes are formed of Crown Glaſs. Even *Flint* Glaſs, when uſed for the Eye-glaſſes to Reflecting Teſeſcopes, will always ſhew Objects too yellow, as neither the Flint Glaſs nor the Metals are ſufficiently white. But the Combination of the Colour of the *Crown* Glaſs, and of the Light reflected from the Metals, will always ſhew Objects of their true natural Colour, and totally free from all dingy or yellowiſh Tinge. I muſt add alſo that *Crown* Glaſs is much more free from Veins than Flint Glaſs, and therefore much preferable. I have alſo been informed by a Gentleman of *Stourbridge*, in *Worceſterſhire*, who is a Glaſs-maker, that *Crown* Glaſs is the moſt pure Glaſs made in this Kingdom, and alſo tranſmits more light than even *Flint* Glaſs, as Objects may be ſeen through a much thicker Piece of Crown than Flint Glaſs. This Circumſtance may perhaps be owing to the Quantity of Lead which enters the Compoſition of *Flint* Glaſs, which, by rendering it more denſe than any other Kind of Glaſs, makes it reflect more, and conſequently tranſmit fewer Rays of Light. Be this as it will, I can affirm from my own Experience, that *Crown* Glaſs is much preferable to Flint Glaſs for the Eye-glaſſes of all Reflecting Teleſcopes.

To try the Figure of the great Speculum.

MR. *Mudge*, in the Philoſophical Tranſactions, has given a Method to try the Figure of the great Speculum (for the ſmall Mirror is always ſpherical) by circular Apertures of Paſteboard applied to the Mouth, or the Object End of the Teleſcope; but this End may be much more eaſily obtained, without the Trouble of uſing Diaphragms of Paſteboard, barely by looking through the Teleſcope, and by viewing, at a proper Diſtance (50 or 100 Yards, for Inſtance) a Circle of Half an Inch or an Inch in Diameter, with a pretty broad black Margin to it. Adjuſt the Teleſcope ſo as to ſhew the Circle as diſtinct as poſſible; turn then the Screw which moves the ſmall Mirror, either to the Right or Left Hand, and you will ſee a regular dark Haze round the Circle, becoming broader and broader as you continue turning the Screw: Then if the Haze is more diſtinct, and the Edge of it better defined, when you turn the Screw from the Place of diſtinct Viſion towards the Right Hand, than when it is turned from diſtinct Viſion towards the Left Hand, the Figure of the great Metal is *ſpherical*; if the black Haze is moſt diſtinct when the Screw is turned towards the Left Hand, it is *hyperbolical*, or beyond the Parabola; but if the Haze and the Edges of it are equally diſtinct on both Sides the true Focus or Point of diſtinct Viſion, which the Eye will judge moſt accurately, then, in ſuch Caſe, the great Speculum has the true *parabolic* Curve required. Theſe, and the following Directions concerning the Method to center the Mirrors, are ſuited to a GREGORIAN Reflector, but for a CASSEGRAIN Teleſcope they muſt be reverſed.

To center the Mirrors.

IT is of the utmoſt Conſequence to the Perfection of Reflecting Teſeſcopes that the Mirrors be truly parallel to each other, and alſo that the Centers of them, together with the Centers of the Eye-glaſſes be all in one direct Line; viz. in the Axis of the Tube. Indeed, unleſs theſe Particulars are attended to, the Inſtrument will prove defective and faulty, even though the Mirrors have the moſt exquiſite Figure poſſible given to them. That truly excellent Artiſt, the late ingenious Mr. *James Short*, always took the greateſt Care to adjuſt and center the Metals of his Teleſcopes; and, to prevent them from being deranged by any Accident, he always marked the upper Part of the great Mirror by a black Line, and faſtened the Screws on the Back of the ſmall Metal with common ſoft Solder. Mr. *Mudge*, in the Philoſophical Tranſactions, very juſtly adviſes us to turn the great Mirror in its Cell, and examine in what Situation it is moſt diſtinct: But he has given us no Directions how we are to place the Metals parallel to each other, at the ſame time that their Centers are exactly in the Axis of the Tube. To ſupply theſe Omiſſions, I ſhall now point out ſuch Methods as I have always found excellent for thoſe Purpoſes.

I. *To adjuſt the Arm which carries the ſmall Speculum.*

Extend Two fine Threads or Wires acroſs the Aperture of the Tube at right Angles, ſo as to interſect each other exactly in the Axis of the Teleſcope; before the Arm is finally faſtened to the Slider, place it in the Tube, and through the Eye-piece (without Glaſſes) the Interſection of the Croſs-wires muſt be ſeen exactly in the Center of the Hole of the Arm. When this Exactneſs is obtained, let the Arm be firmly rivetted and ſoldered to the Slider.

II. *To place the ſmall Mirror parallel to the large Speculum.*

Divide the Circumference of the Mouth-piece of the Tube of the Teleſcope into Four equal Parts. Provide a Circle of Paſteboard about One Half or Two Thirds of the Diameter of the Mouth of the Tube. Procure alſo a narrow Strip of Wood, whoſe Length is exactly equal to the Inſide Diameter of the Mouth of the Tube; divide it into Two equal Parts, and to this Middle Point faſten the Center of the Paſteboard Circle by a ſmall Pin. Apply now this ſmall Apparatus to the Two oppoſite Marks made on the Mouth of the Tube; by this Means the Center of the Paſteboard Circle will coincide with the Center of the Tube. Care alſo muſt be taken that the Paſteboard Circle be in the ſame Plane with the Mouth of the Teleſcope, or, which is the ſame Thing, at right Angles to its Axis; which is eaſily effected by applying the Edge of a Ruler acroſs the Mouth of the Teleſcope, and by making any of the Diameters of the Paſteboard Circle touch the Edge of the Rule. Take now the Eye-glaſſes from the Eye-tube, and ſcrew that Tube, without its Glaſſes, in its proper Place: Direct then the Mouth of the Teleſcope towards a Window or the Sky, apply your Eye to the ſmall Hole in the Eye-tube, and obſerve whether the Ring of Light in the ſmall Mirror is exactly of the ſame Breadth in every Part of it, which will always be the Caſe when the ſmall Metal is parallel to the great Speculum; in all other Poſitions of the ſmall Speculum, the Ring of Light in it (which is only the reflected Image of that Part of the great Mirror which is not hid by the Paſteboard Circle) will appear of different Breadths in different Parts of its Circumference: Adjuſt now the ſmall Mirror by the Three Screws at its Back, till the Ring of Light appears, in every Part, exactly of the ſame uniform Breadth; and thus, by a few Trials, the Face of the ſmall Metal may eaſily be placed parallel to the Face of the great Speculum.

III. *To place the Center of the ſmall Mirror in the Axis of the Tube.*

Put the circular Paſteboard on the Mouth of the Tube, as before; then apply the Eye to the Eye-hole (the Eye-glaſſes being removed) and obſerve whether the outer Edge of the Ring of Light in the ſmall Mirror, when adjuſted by the preceding Rule, is equi-diſtant in every Part of its Circumference from the Edge of the ſmall Metal: In ſuch Caſe, the Center of the ſmall Mirror is coincident with the Axis of the Teleſcope; but if the outer Edge of the Ring of Light in the ſmall Speculum is nearer to the Edge of it in ſome Part of its Circumference than in others, or, in other Words, if the dark Part ſurrounding the Ring of Light in the ſmall Speculum has not the ſame Breadth in every Part of its Circumference, then the Center of the ſmall Metal is not coincident with the Axis of the Tube, but muſt be raiſed higher or depreſſed lower, muſt be put towards the Right Hand, or towards the Left, as ſhall appear neceſſary. The eaſieſt Method to perform this, is to make the Screw, which goes through the Hole in the upright Stem of Braſs which carries the ſmall Metal, with a broad Shoulder to it, and to make the Hole in the Center of the Braſs Stem pretty large (but not ſo large as the Shoulder of the Screw) by which Means the ſmall Mirror may be raiſed or depreſſed, may be placed a little to the Right Hand, or towards the Left, as is found to be moſt proper, and may be retained in any of thoſe Poſitions by the three ſmall Screws that bear againſt the Back of the ſmall Speculum.——This and the preceding Adjuſtment muſt be repeated by Trials, till the Ring of Light in the ſmall Mirror is of One uniform Breadth in every Part of its Circumference, and, at the ſame Time, the outer Edge of the Ring of Light is equi-diſtant from the Edge of the ſmall Metal; for then, and then only, the Face of the ſmall Mirror is parallel to the Face of the great Speculum, and, at the ſame Time, its Center is coincident with the Axis of the Tube; or the Centers of the Eye-glaſſes, and the Centers of the great and ſmall Specula, are in One right Line.

N. B. When the ſmall Mirror has been adjuſted, by the preceding Directions, thoſe two Adjuſtments may be examined and rectified to the utmoſt Degree of Preciſion by the following Method.

Put up a Circle of Half an Inch or an Inch in Diameter, with a broad black Margin to its Circumference, at the Diſtance of Fifty or a Hundred Yards from the Teleſcope. Turn the Screw, which carries the Braſs Stem and the ſmall Mirror, nearer to or farther from the great Speculum, and you will obſerve, if the Metals are centered very well, the Margin of the Circle will appear to become leſs and leſs, ſo as to form continually a leſs Circle, till at laſt, as you continue turning the Screw, it will terminate in a black Spot in the Middle of the true Circle (which will ſtill continue viſible) with a large broad and black Haze round it, equally broad in every Part of it. If the black Spot appears on the Margin of the true Circle, and conſequently the black Haze is not equally broad round the true Circle, then the Mirrors are not exquiſitely centered, but the ſmall Metal muſt be adjuſted by the three ſmall Screws at the Back of it, by ſcrewing up, in a very ſmall Degree, the ſmall Screw which is diametrically *oppoſite* the black Spot, or on the other Side the Center of the Circle on whoſe Margin * the Spot appears. When the Metals are found to be exquiſitely centered, faſten the three ſmall Screws at the Back of the ſmall Speculum, with common ſoft Solder, to prevent them from drawing, or giving Way. Put up now a Watch Paper, or any other printed Paper, with Letters or Figures upon it of different Dimenſions, ſome of which ſhould be very ſmall, at the Diſtance of at leaſt Sixty Times the focal Length of the great Speculum from the Teleſcope. Turn the large Mirror in its Cell, about the Eighth Part of a Revolution each Time, and obſerve in which of thoſe Poſitions the minute Figures or Letters upon the Paper are moſt diſtinct: Mark then, with a black Stroke, the upper Part of the Back of the great Speculum, and a correſponding Part upon the Inſide of the Braſs Tube, adjoining to the black Stroke on the Back of the Mirror; by which Means, if the great Speculum is taken out of its Cell at any Time, it may eaſily be replaced exactly in the ſame Poſition.—The Mirrors may alſo be examined by Means of any of the fixt Stars, particularly by thoſe of the *Firſt* Magnitude; for if the Mirrors are truly centered and adjuſted to their beſt Poſition, a fixed Star, when made indiſtinct by the adjuſting Screw on the Side of the Tube, ſhould always appear, in Reflecting Teleſcopes, as a truly *round* Circle of Fire with a black Spot exactly in its Center; and when the Teleſcope is adjuſted to diſtinct Viſion, the Star ſhould appear, if the Teleſcope is excellent, and the State of the Air favourable, exactly *round*, and totally free from all Irradiations, or falſe Rays and Glare. Indeed I can aſſert, from Experience, that no Object is ſo proper to determine the Excellence of Teleſcopes as the fixt Stars; as the leaſt Irregularity in the Figure of the Metals in Reflecting Teleſcopes, or of the Object-glaſs in Acromatics, is rendered by them exceeding conſpicuous by a falſe Glare, and by their not appearing perfectly *round*. The ingenious Mr. *Wm. Herſchell* of *Bath*, F. R. S. a Gentleman well known in the aſtronomical World, has diſcovered near 300 *double* and *treble* Stars *, many of which are exceeding minute ones, and which, at the ſame Time that they will afford us an Opportunity to prove the Goodneſs of our Teleſcopes, ſhew the Excellence of his own †, and illuſtrate the Obſervation of the Royal Pſalmiſt, that "*The* "*Heavens declare the Glory of God, and the Firmament ſheweth his Handy-work.*"

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* When the Metals are centered exceeding near, but not accurately true, the true Margin of the Circle will appear too broad in ſome One Part of its Circumference; that is, the black Line, forming the Circumference of the true Circle, will not appear equally broad in every Part of it. In ſuch a Caſe, ſcrew up the ſmall Screw at the Back of the ſmall Speculum, which is *oppoſite* the Part of the Circumference of the Circle which appears too black, or too broad.

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* See Philoſ. Tranſ. Vol. LXXII.

† The Diameter of the great Mirror of Mr. *Herſchell*'s longeſt Reflecting Teleſcope (which is of the NEWTONIAN Conſtruction) is 12 Inches, its focal Diſtance is 20 Feet, and its magnifying Powers, for the fixt Stars, are from 300 to 6000 Times.

POSTSCRIPT.

AS the following Table of the Apertures, Powers, and Prices of Reflecting Teleſcopes, conſtructed in the *Gregorian* Form, by the late ingenious Mr. *James Short*, is very ſcarce, it may not be unacceptable to my Reader, if I here inſert it.

Number.	Focal Length in Inches.	Diameter of Aperture in Inches.	Magnifying Powers.	Prices. Guin.
1	3	1,1	1 Power of —— 18 Times	3
2	4½	1,3	1 —— —— 25——	4
3	7	1,9	1 —— —— 40——	6
4	9½	2,5	2 —— — 40 & 60——	8
5	12	3,0	2 —— — 55 & 85——	10
6	12	3,0	4 —— 35, 55, 85, & 110——	14
7	18	3,8	4 —— 55, 95, 130, & 200—	20
8	24	4,5	4 —— 90, 150, 230, & 300—	35
9	36	6,3	4 ——100, 200, 300, & 400—	75
10	48	7,6	4 ——120, 260, 380, & 500—	100
11	72	12,2	4 ——200, 400, 600, & 800—	300
12	144	18,0	4 ——300, 600, 900, & 1200	800

Mr. *Short*, in the above Table, *always* greatly over-rated the higheſt Power of his Teleſcopes. By *Experiment* they were found to magnify much leſs than expreſſed in his Paper. Mr. *Short* finiſhed two or three Teleſcopes of the *Gregorian* Form, of 18 Inches Focus, with 4,5 Inches Aperture, and Power 170. He alſo made *one* Teleſcope, of the *Caſſegrain* Form, of 24 Inches Focus, with 6 Inches Aperture, and Power 355. But it was very indiſtinct with that Power. The greateſt Magnifier it bore, with ſufficient Diſtinctneſs, was 231 Times. He alſo made ſix Teleſcopes of the ſame Focus of the *Gregorian* Form, which bore the uſual magnifying Powers very well.

A TABLE of the Apertures, Powers, &c. of Teleſcopes of the NEWTONIAN Conſtruction, in which the Figure of the Great Metal is ſuppoſed to be truly *ſpherical*.

Foc. Diſt. of Concave Metal.	Aperture of Concave Metal.	Sir Iſaac Newton's Numbers.	Foc. Diſtance of Single Eye-Glaſs.	Magnifying Power.
Feet.	Inc. Dec.		Inch. Dec.	
½	0,86	100	0,167	36
1	1,44	168	0,199	60
2	2,45	283	0,236	102
3	3,31	383	0,261	138
4	4,10	476	0,281	171
5	4,85	562	0,297	202
6	5,57	645	0,311	232
7	6,24		0,323	260
8	6,89	800	0,334	287
9	7,54		0,344	314
10	8,16	946	0,353	340
11	8,76		0,362	365
12	9,36	1084	0,367	390
13	9,94		0,377	414
14	10,49		0,384	437
15	11,04		0,391	460
16	11,59	1345	0,397	483
17	12,14		0,403	506
18	12,67		0,409	528
19	13,20		0,414	550
20	13,71	1591	0,420	571
21	14,23		0,425	593
22	14,73		0,430	614
23	15,21		0,435	635
24	15,73	1824	0,439	656

As Teleſcopes of Sir *Iſaac Newton*'s Conſtruction are now found (particularly by the late exquiſite Obſervations of Mr. *Herſchell* of *Bath*) to perform moſt excellently in the *Minutiæ* of Aſtronomy, eſpecially if ſmall Apertures and long Foci are made Uſe of, I have added the foregoing Table, chiefly taken from Dr. *Smith*'s Optics, vol. i. p. 148, and have continued it on from 17 to 24 Feet focal Diſtance of the great Mirror. I have alſo annexed to it Sir *Iſaac Newton*'s Numbers, by means of which the Apertures of Reflecting Teleſcopes, of any Conſtruction, may be eaſily computed. See Appendix to *Gregory*'s Optics, p. 229, or Philoſophical Tranſactions, N° 81.

It may be neceſſary to mention, that the preceding Table was conſtructed by uſing the Dimenſions of the Middle Aperture and Power of Mr. *Hadley*'s excellent *Newtonian* Teleſcope as a Standard; *viz.* Focal Diſtance of great Mirror 62½ Inches — Aperture of Concave Metal 5 Inches, and Power 208 Times. Mr. *Herſchell* chiefly makes Uſe of a *Newtonian* Reflector, the focal Diſtance of whoſe great Mirror is 7 Feet, its Aperture 6,25 Inches, and Powers 227 and 460 Times, though ſometimes he uſes a Power of 6450 for the fixt Stars.

Note, If the Metals of a *Newtonian* Teleſcope are worked as exquiſitely as thoſe in Mr. *Herſchell*'s Seven Feet Reflector, the higheſt Power that ſuch a Teleſcope ſhould bear, with perfect Diſtinctneſs, will be given by multiplying the Diameter of the great Speculum by 74; and the focal Diſtance of the ſingle Eye-glaſs may be found by dividing the focal Diſtance of the great Mirror by the magnifying Power: Thus, $6{,}25 \times 74 = 462$ the Mag. Power; and $\frac{7\times12}{462} = 0{,}182$ of an Inch, the foc. Diſt. of the ſingle Eye-glaſs required.

To grind and poliſh the ſmall Speculum of a NEWTONIAN *Teleſcope truly flat.*

IT may perhaps be neceſſary to inform thoſe who would wiſh to finiſh Teleſcopes of the *Newtonian* Form, that the ſmall *elliptical* plane Mirror may be ground truly *flat* by making Uſe of Two or more Tools conſiderably larger than the Speculum intended to be finiſhed upon them, after it is brought as near the Figure as can be done upon a ſmall Tool of Lead with fine Emery. The Tools, or Beds of Hones, ſhould be no leſs than Six Inches in Diameter. The Figure of the Tools is not allowed to be completed, till the Speculum can be firſt highly finiſhed upon One of them, and afterwards be applied to another without receiving any Change. The laſt Half Dozen Strokes ſhould be in the Direction of the longer Axis of the Ellipſis. When this is perfected, it muſt be poliſhed upon the Pitch Poliſher of a circular Form, whoſe Diameter is about *One-tenth* Part greater than the tranſverſe Axis of the Speculum. For this Method of figuring the ſmall Speculum truly *flat*, I am obliged to that excellent Aſtronomer Mr. *Herſchell* of *Bath*.

To find, by Experiment, the magnifying Power of any Teleſcope.

MANY Methods have been contrived to determine experimentally the magnifying Power of any Teleſcope. That excellent Artiſt Mr. *Ramſden* ſhewed me, ſome time ago, a ſmall Inſtrument, of his own Invention, to meaſure the Diameter of the emergent Pencil of Rays, at the Eye-hole, to the utmoſt Degree of Preciſion. By dividing the Diameter of the great Mirror in a Reflecting Teleſcope, or the Diameter of the Object-glaſs in a Refractor, by the Diameter of the emergent Pencil of Rays, determined by that Inſtrument, the magnifying Power will then be given. But as that Inſtrument, conſtructed chiefly upon the Principle of Mr. *Dollond*'s Object-glaſs Micrometer, is ſomewhat * expenſive, and therefore may not be found in the Hands of every One who is poſſeſſed of a Teleſcope; I ſhall lay down a plain and eaſy Method by which I could always diſcover the Powers of my Teleſcopes very readily and with ſufficient Accuracy.

At the Diſtance of One or Two hundred Yards from the Teleſcope put up a ſmall Circle of Paper of any determined Diameter, an Inch for Inſtance: Upon a Card, or any Piece of ſtrong Paper, through which the Light cannot be eaſily tranſmitted, draw Two black parallel Lines, whoſe Diſtance from each other is exactly equal to the Diameter of the ſmall Circle. Adjuſt the Teleſcope to diſtinct Viſion, and through it view the aforeſaid ſmall Circle with One Eye, and with the other Eye, open alſo, view at the ſame time the Two parallel Lines. Let the parallel Lines be then moved nearer to or further from your Eye, till you ſee them appear exactly to cover the ſmall Circle viewed in the Teleſcope. Meaſure now the Diſtance of the ſmall Circle, and alſo of the parallel Lines, from your Eye. Divide then the Diſtance of the former by that of the latter, and you will have the magnifying Power of the Teleſcope required.

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* Mr. *Ramſden* informed me that the Price of One of his ſmall Inſtruments to determine the Power of any Teleſcope would be about *Three* Guineas. Whether any other Optician makes theſe Inſtruments, as invented by Mr. *Ramſden*, I cannot tell, having never ſeen any other than that which Mr. *Ramſden* ſhewed to me.

Two other Methods to determine, by *Experiment*, the Power of any Teleſcope are given in Dr. *Smith*'s Optics, in the Notes upon Art. 109 and 485.

* *To determine the Size and Place of the Eye-hole in a ſingle or compound Eye-piece of a Reflecting Teleſcope.*

IT is abſolutely neceſſary for perfect Viſion that the Eye ſhould be applied to a ſmall Hole of a certain Dimenſion placed exactly in the Focus of the ſingle Eye-glaſs, if the Eye-piece conſiſts of † One Glaſs only, or elſe in the compound Focus of the Glaſſes, if it is conſtructed with Two, as is moſt commonly practiſed. If the ſmall Eye-hole is not exactly in the proper Place and alſo of the true Size, the Teleſcope will prove faulty, as it will always either take in foreign Light, and by that Means the Object will appear very indiſtinct, or elſe it will cut off many of the Rays which ſhould come to the Eye, and then the Object will not appear ſo vivid as it ought to do. To rectify therefore its Size and Place let the following Rules be obſerved.

Let the Diſtance of the Eye-hole from the Eye-glaſs, if it is a ſingle One, be put, as near as can be attained by Meaſure, equal to the focal Diſtance of the Eye-glaſs; but if it is a compound Eye-glaſs, the Diſtance of the Eye-hole from the Glaſs neareſt the Eye may be found thus: Multiply the Difference between the focal Diſtance of the Glaſs next to the Mirror and the Diſtance of the Two Eye-glaſſes by the focal Diſtance of the Glaſs neareſt to the Eye, and divide this Product by the Sum of the focal Diſtances of the Two Glaſſes leſſened by their Diſtance, and you will have the compound focal Diſtance required. Example. If the focal Diſtance of the Glaſs neareſt to the Mirror is 3 Inches, the focal Diſtance of the Glaſs neareſt the Eye is 1 Inch, and their Diſtance from each other is 2 Inches, then the compound focal Diſtance from the Eye-glaſs will be $\frac{\overline{3-2}\times 1}{3+1-2} = \frac{1}{2}$ an Inch.

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* Theſe Directions might have been inſerted, perhaps with more Uniformity, immediately after the Directions for *the Eye-glaſſes of Reflecting Teleſcopes*, p. 30; but as this Treatiſe is already ſet and corrected to this Place, I am neceſſitated to inſert it here.

† Some Aſtronomers prefer an Eye-piece of One double convex Glaſs only for the higher Powers of their Teleſcopes, as it will tranſmit more Light than can paſs through Two Glaſſes.—In Mr. *Herſchell's* Teleſcopes of the *Newtonian* Form, the Eye-pieces for the greateſt Powers conſiſt only of One ſmall double convex Glaſs.

The Diameter of the Eye-hole may alſo be determined by dividing the Diameter of the great Speculum by the magnifying Power of the Teleſcope. Thus, if the Aperture of the Teleſcope is 4 Inches and Power 150, the Diameter of the Eye-hole will be 0,027 of an Inch nearly, or $\frac{4}{150} =$ 0,02666, &c.

Having now found the Place and Size of the Eye-hole *by Calculation* nearly, the true Place and Size muſt be determined *accurately by Experiment*, ſince our Meaſures of the Foci, Diſtances, &c. of the Glaſſes cannot be found with ſufficient Accuracy.

With a ſmall convex Glaſs of an Inch or an Inch and Half focal Diſtance view the Picture of the large Mirror in the Eye-hole; hold the convex Glaſs as ſteady as you can in one Hand, and move your Eye upwards or downwards, towards the Right Hand or towards the Left; then if the Picture of the large Metal in the Eye-hole has a Motion in the *ſame Direction* with the Eye, the Focus of the Eye-glaſs, whether ſingle or compound, is between the Eye-hole and the Eye-glaſs; but if the Picture of the great Speculum in the Eye-hole appears to move *contrary* to the Motion of the Eye, then the true Focus is between the Eye and the Eye-hole. In the former Caſe the Eye-hole muſt be brought *nearer* to the Eye-glaſs, in the latter Caſe it muſt be removed *farther* from it, till you perceive the Picture of the great Mirror become Stationary, or without any Motion, in whatever Direction the Eye is moved; for then and then only the Eye-hole is *moſt accurately* in the Focus of the ſingle or compound Eye-glaſs.

The Diameter of the Eye-hole may alſo be determined exactly by viewing, with the ſmall convex Glaſs held in the Hand, as in the preceding Operation, the exact Size of the Picture of the great Metal in the Place of the Eye-hole, determined accurately by the foregoing Direction. If the Area of the Eye-hole appears a ſmall Degree larger than the Area of the emergent Pencil of Rays, or the Picture of the great Speculum, then it is ſufficiently large to tranſmit all the Rays of Light which come from the great Metal. But if the Area of the Eye-hole is found to be leſs than the Area of the Picture of the great Speculum, the Eye-hole muſt be enlarged till its Diameter ſhall be found equal to, or rather a little larger than the Diameter of the emergent Pencil of Rays.

THE END.